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PATENT
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PARTIAL PREMIX DUAL CIRCUIT FUEL INJECTOR

GOVERNMENT RIGHTS

- 5 [001] The invention described herein was made in the performance of work under NASA Contract No. NAS3-27752 awarded by NASA Glenn Research Center, and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958 (42 U.S.C. 2457). The Government has certain rights in this invention.

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BACKGROUND OF THE INVENTION

- 15 [002] This invention relates generally to fuel injectors used in gas turbine engine combustors and, in particular, to a fuel injector design primarily for aerospace applications, which produces a stable flame at low power, generating low CO and UHC pollutants, and also provides enhanced fuel-air mixing to reduce NOx emissions at high-power.

- 20 [003] Atmospheric pollution concerns and effects worldwide have led to enactment of increasingly stricter emission controls and standards requiring most industries to significantly reduce the emissions of pollutants. The strict emission controls have required implementation of numerous design changes in gas turbines used for industrial, power generation and propulsion applications. Thus typical gas turbine engines are now required to operate efficiently over a wide range of conditions while at the same time producing minimal quantities of
- 25 noxious emissions. The common precursors to gas turbine engines cause atmospheric pollution include Carbon Monoxide (CO), and Unburned

Hydrocarbons (UHC) at low engine power conditions, and Nitrous Oxide (NOx) at intermediate and high engine power conditions.

5 [004] Reductions in gas turbine emissions of NOx have been obtained primarily by the reduction of flame temperatures in the combustor. Some of the techniques employed include lean burn pre-mix combustors in which the fuel to air ratio is reduced as far as possible in the higher operating range; staged combustors, whereby fuel is admitted to the combustion chamber at different axial locations thereby staging the combustion process; lean-direct injection involving methods of injecting fuel and air into a combustion chamber where the mixture is fuel-lean, or below the stoichiometric fuel/air ratio; and other related techniques known to those skilled in the art as "rich burn" and "quick quench".

10 [005] Gas turbine propulsion engines employ annular and can-type combustors to burn fuel. The fuel is metered and sprayed into the combustor through a single or a plurality of fuel nozzles along with combustion air having a designated amount of swirl. In the typical gas turbine engine, flame stability, variable cycle operation, and emission control dominate combustor design requirements. The characteristics of a given fuel injector under light-up and low speed conditions are different to those under full power conditions. Consequently a fuel injector is often a compromise between two designs to enable it to operate under both of these conditions.

15 [006] Typically, fuel is supplied through one supply duct under starting or low power conditions and through another or through both fuel supply ducts under high power conditions. During light up and low speed conditions, only the pilot fuel injectors are used whereas both the pilot and the main fuel injectors are used under higher speed conditions. The pilot combustion stage is usually long in comparison with the main combustion stage. Consequently, the residence time of the fuel in the pilot stage is comparatively long, limiting emissions of hydrocarbons and carbon monoxide. Conversely, the residence time of the fuel in the main stage is comparatively short, limiting emissions of the oxides of nitrogen.

[007] Many techniques have been utilized in the prior art to enable efficient gas turbine engine operation over a wide range of conditions while at the same time producing minimal quantities of noxious emissions. Of particular interest in this regard are the following references and examples:

5 **[008]** U.S. Patent No. 4,701,124 discloses a can-type combustor intended for industrial applications and designed to use oil or natural gas as the fuel. The fuel is injected at a compound angle in the main fuel chamber at the air swirler vane exit plane.

[009] U.S. Patent No. 5,062,792 also targets industrial burners and uses oil
10 or natural gas as the fuel. In this design, the oil is used to fuel the pilot circuit, while the natural gas is used to fuel the main circuit.

[0010] U.S. Patent No. 5,069,029 involves a staged combustor, wherein fuel is admitted to the combustion chamber at different axial locations, thereby staging the combustion process. Axial-type air swirlers are utilized for both pilot
15 and main fuel circuits.

[0011] U.S. Patent No. 5,816,050 discloses a can-type combustor with pilot fuel system that injects the fuel axially into the swirling air stream, which is kept separate from the main air stream by a containment wall. Separate fuel injectors are utilized for the pilot and main systems, the latter injecting the fuel
20 near the outer diameter of the air swirler.

[0012] U.S. Patent No. 5,862,668 teaches a radial-staged combustion system, whereby the pilot system is operated at low power (inward and radial location) and the main and pilot are operated at high power conditions. The combustor is considered a premix type system due to the longer residence time
25 of fuel and air in the premixing tubes.

[0013] U.S. Patent No. 6,151,899 involves a can-type combustion chamber whereby main fuel is injected axially into the swirling air passage, and pilot fuel is injected in two discreet axial and radial locations.

[0014] U.S. Patent No. 6,158,223 also teaches a can-type combustion
30 chamber providing for a pilot fuel injection point in the same plane as the main

fuel/air injection point. The design utilizes a plurality of main air swirlers for each pilot air swirler.

[0015] U.S. Patent Application No. 09/492,678, filed January 27, 2000, for Combustor with Fuel Preparation Chambers, by the same inventor as this application, and also assigned to the assignee of this application, discloses an annular combustor having fuel preparation chambers mounted in the dome of the combustor with the objective of uniformly mixing fuel and air so as to reduce NOx formed by the ignition of the fuel/air mixture.

[0016] With the exception of the last reference, none of the above-cited prior art is specifically intended for lightweight, aerospace type applications, and some suffer from one or more of the following disadvantages:

- a) aerospace type fuels cannot be utilized.
- b) fuel-air residence times prior to entering the combustion chamber are relatively long, thus increasing the danger of autoignition or flashback situations, which are a safety concern for aerospace applications.
- c) complexity in fabrication and operation.
- d) inability to retrofit the system on existing engines.
- e) the fuel injection system is usable for can type or annular combustors, but not for both.

[0017] For the foregoing reasons, as can be seen, there is a need for a simple, retrofittable, gas turbine engine fuel injector system primarily for aerospace applications, which produces a clean stable flame at low power, provides enhanced fuel-air mixing to reduce noxious emissions at high-power, and can be employed on both can-type and annular type combustion systems.

SUMMARY OF THE INVENTION

[0018] In one aspect of the present invention, a fuel injector system is provided to produces a stable flame at low power operations, generating low CO and UHC pollutants.

5 [0019] In another aspect of the present invention, a fuel injector system is provided to produce enhanced fuel-air mixing to reduce NOx emissions at intermediate and high power operations.

10 [0020] In a further aspect of the present invention, a gas turbine engine fuel injection system, comprised of a single fuel injection body incorporating both pilot circuit and main circuit fuel injectors, is provided that produces minimal quantities of CO, UHC and NOx emissions.

[0021] In yet another aspect of the present invention, a simple, low cost gas turbine engine fuel injection system is provided that is capable of producing minimal quantities of noxious emissions, and which can be retrofitted into existing products, including engines for aerospace applications.

15 [0022] In a still further aspect of the present invention, a gas turbine engine fuel injection system is provided that is capable of producing minimal quantities of noxious emissions, and which can be utilized on annular as well as can-type combustors.

20 [0023] The present invention is comprised of one fuel injection body to supply both pilot and main fuel systems. The fuel injection body is further comprised of a pilot fuel circuit and a main fuel circuit, both of which inject fuel at essentially the same axial and radial location. The recessed pilot fuel injection site is along the combustor centerline into a swirling air passage produced by axial air swirlers. The main fuel is injected radially through a plurality of injection sites, at
25 a compound angle, into the inner diameter of a swirling air passage produced by radial air swirlers. One main air swirler is utilized for each pilot air swirler. The fuel/air residence time prior to entering the combustion chamber is relatively short, minimizing the likelihood of auto ignition.

30 [0024] A method for producing a low noxious emission gas in a combustor is also disclosed. The method includes injecting pilot circuit fuel spray into a

swirling passage along the combustor centerline for low power operations. For intermediate and high power operations, main circuit fuel spray, together with pilot circuit fuel spray, is discharged into a radial swirler air passage, and thereafter fluidly communicates with a single combustion chamber. The swirling mixture of pilot circuit and main fuel and air enters the combustion chamber, is expanded, and ignited to form low emission gas.

[0025] These and other objects, features and advantages of the present invention, are specifically set forth in, or will become apparent from, the following detailed description of a preferred embodiment of the invention when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Figure 1 is a longitudinal cross section of a gas turbine engine combustor assembly having the inventive partial premix dual circuit fuel injector;

[0027] Figure 2 is a perspective view of the inventive partial premix dual circuit fuel injector;

[0028] Figure 3 is a cross section of the combustor assembly showing air and fuel flow patterns during low power operation; and

[0029] Figure 4 is a cross section of the combustor assembly showing air and fuel flow patterns during intermediate and high power operation.

DETAILED DESCRIPTION OF THE INVENTION

[0030] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best defined by the appended claims.

[0031] Referring to Figure 1, there is shown a longitudinal cross section of a gas turbine engine combustor assembly 10, having an upstream end 11 and a downstream end 12. The combustor fuel mixing zone 13 is located along the downstream end 12. The combustor assembly 10 is cylidrically shaped and
5 bounded along its longitudinal outer periphery by a combustor outer casing housing 14 which is attached along its internal, upstream end 11 to an annular sheet metal dome 16. The sheet metal dome 16 serves as a connecting member as well as a shield, protecting upstream end 11 components from exposure to excessive temperatures generated at the combustor. Thermal
10 protection is provided by a heat shield 17 and cooling skirt 18 as well as a plurality of circumferentially disposed dome cooling nozzles 19 which dispense cooling air flow 19A from the gas turbine engine compressor stage.

[0032] Still referring to Figure 1, there is shown an annular swirler housing 26 rigidly connecting the sheet metal dome 16 to a fuel injector body 15 which is
15 located along the longitudinal centerline 10A of the combustor assembly 10. The radial air swirler housing 26 accommodates a plurality of radial swirlers 27 peripherally located along the upstream end 11, each said radial swirler 27 provided to bring air flow, designated by arrows 28, supplied under pressure from a compressor of the gas turbine engine (not shown). The radial swirler 27
20 is adapted to bring air flowing inwardly radially, designated by arrows 29, therethrough to rotate through and around the radial swirler passage 30 and into the combustion chamber's fuel mixing zone 13.

[0033] The fuel injector body 15 incorporates both the pilot circuit fuel injection and the main circuit fuel injection systems. Pilot circuit burner fuel
25 enters the pilot circuit fuel nozzle 21 from the upstream end 11 along the combustor centerline 10A and into the pilot circuit fuel nozzle 21 where it is atomized and thereafter dispersed, through the convergent-divergent end 15A, into the fuel mixing zone 13 in the direction essentially as shown by the pilot circuit fuel flow arrows 25. A plurality of axial pilot circuit air swirlers 22, located
30 radially outboard of the pilot circuit fuel nozzle 21, swirls air flow 23 provided

from a compressor of the gas turbine engine (not shown), and routes it, as shown by arrows 24, to the convergent-divergent end 15A, where it will mix with the pilot circuit fuel flow 25, to be thereafter ignited.

[0034] Main circuit burner fuel 31 enters the main circuit fuel nozzle 32 from the upstream end 11, is routed through a passageway 33 bored approximately parallel to the combustor assembly centerline 10A, and rotated approximately 90 degrees to exit the main circuit fuel nozzle 32 at an outwardly radial direction. The main circuit fuel flow represented by arrows 34 is atomized as it exits the main circuit fuel nozzle 32, is thereafter mixed with the radial swirler air flow 29 in the radial swirler passage 30, and is then routed to the fuel mixing zone 13 to be thereafter ignited. In the preferred embodiment, main fuel is introduced through at least four main circuit fuel nozzles 32 symmetrically spaced around the outer periphery of the fuel injector body 15.

[0035] Figure 2 is a perspective view showing various central elements of the partial premix dual circuit fuel injector assembly. For clarity purposes, the combustor outer casing 14 housing is not shown. The radial swirler exit plane 30A and radial swirler attachment (to combustor dome) flange 30B establish the outer boundary of the fuel injector assembly. Multiple main fuel circuit radial swirlers 27 are located along the entire outer periphery adjacent to the base of the radial swirler passage 30. The fuel injector body 15 is centrally located and is comprised of the recessed pilot circuit fuel nozzle 21 which is itself peripherally surrounded by a plurality of axial pilot circuit air swirlers 22. Two main circuit fuel nozzles 32 are shown located along the external periphery of the fuel injector body 15. In the preferred embodiment, at least four symmetrically spaced main circuit fuel nozzles 32 are used. Alternate embodiments may use fewer or additional main circuit fuel nozzles 32.

[0036] Referring now to Figure 3, there is shown a cross section of the combustor assembly showing air and fuel flow patterns during low power operation. Pilot circuit fuel entering the fuel mixing zone 13 is sprayed as represented by arrows 25. The swirler air flow 24 produced by the axial pilot

circuit air swirlers 22 mixes with the fuel and is caused to recirculate in the general direction shown by arrows 35 forming a vortex recirculation zone 36. When the fuel air mixture is ignited, the fuel rich flame stabilized by the recirculation zone 36, produces high flame temperatures, helping to improve combustor efficiency by completely burning the fuel and eliminating CO and UHC emissions. Flame stabilization is also somewhat aided by the double vortex effect of radial swirler 27 recirculation air, represented by arrows 37, which forms a radial swirler air vortex recirculation zone 38. Main circuit fuel does not flow during low power operation.

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10 **[0037]** Referring now to Figure 4, there is shown a cross section of the combustor assembly showing air and fuel flow patterns during intermediate and high power operation. Fuel entering the fuel mixing zone 13 is sprayed as represented by arrows 25 for the pilot circuit and by arrows 34 for the main circuit. The swirler air flow 24 produced by the axial pilot circuit air swirlers 22 mixes with the pilot circuit fuel and is caused to recirculate in the general direction shown by arrows 35 forming a vortex recirculation zone 36. Radial swirler 27 air flow, represented by arrows 29, mixes with the main circuit fuel flow 34 and the mixture is caused to recirculate in the general direction shown by arrows 39 forming a separate vortex recirculation zone 40. When the pilot circuit and main circuit fuel air mixtures are ignited, the flame stabilized by recirculation zones 36 and 40 produces relatively low flame temperatures since the mixture is fuel lean, with the result that NOx emissions are materially reduced.

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25 **[0038]** The previously described versions of the present invention have many advantages, including:

- a. the capability of utilizing not only aerospace type fuels but other types of fuels as well;
- b. the ability to retrofit the inventive fuel injection system on existing gas turbine engines;

c. the simplicity and corresponding low cost of the apparatus whereby a single fuel injection body incorporating both pilot circuit and main circuit fuel injectors is provided;

5 d. a design which provides for fuel-air residence times prior to entering the combustion chamber to be relatively short, thus reducing the danger of autoignition or flashback situations, which are a safety concern for aerospace applications; and

e. the capability of utilizing the inventive fuel injection system for both can type or annular combustors.

10 [0039] Although the present invention has been described in considerable detail with reference to certain preferred versions thereof, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained therein.